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STANDARDIZATION OF NO. 200 CEMENT SIEVES

BY

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I. INTRODUCTION

The desirability of an improved standard for cement sieves has frequently been questioned on the ground that the fineness test, as ordinarily performed on the 200-mesh sieve, does not determine the quantity of the highly active material in the cement, and the results do not, therefore, necessarily give any indication of the quality of the cement. While this is probably true, it is obviously important from a commercial standpoint that cement furnished on contract according to specifications, and actually meeting the requirements for fineness, should not be rejected because an error has been made in the fineness determination, due to the use of inaccurate sieves or variation in the manipulation of the sieves. Such rejections, resulting in considerable financial loss, have been brought to the attention of the Bureau. The tolerance to be applied on the fineness determination should be such that it will cover all the unavoidable errors of the sieving tests. Experience has shown that the apparently liberal tolerance of 1 per cent previously suggested to cover the errors in fineness determinations on standard 200-mesh sieves, is not great enough, in very many cases, to cover the known variations in the sieves, and an improved standard seems, therefore, not only desirable but necessary.

The most important restrictions in the specifications for standard cement sieves are those which relate to the number of meshes per linear unit of the sieve cloth and to the diameter of the wire from which the cloth is woven. These sieve specifications serve as a guide to the wire cloth manufacturer but contain no reference to the performance of sieves as actually used in fineness determinations, the assumption being that the narrow limits of tolerance imposed would insure a satisfactory uniformity in sieving values.

Until recently no systematic investigation has been undertaken to check the uniformity of fineness determinations of standard sieves nor to establish the relation between measurements of the sieve cloth and the sieving values of these sieves. About two years ago the Bureau of Standards conducted such a series of tests [1] which established the fact that new certified standard

[1] Bureau of Standards, Technologic Paper, No. 29.

sieves differ very considerably in their sieving values, and that no specific relation could be found between the measurements of the sieve cloth and the observed sieving values. In view of this lack of uniformity a further investigation was undertaken, in the course of which it has been ascertained that some unsatisfactory sieves, from the user's point of view, have been certified as standard sieves, and many good ones, from the same point of view, have been rejected. This peculiar condition may be explained by the fact that the specifications for standard sieves, although permitting only the practical minimum of variations in number of meshes and wire diameters, do not limit the dimensions of the individual openings.

The specifications for standard sieves, issued by the Bureau in 1912,[2] contain the following requirements for 200-mesh sieves:

Wire cloth for standard sieves for cement shall be woven (not twilled) from brass, bronze, or other suitable wire and mounted on frames without distortion. The sieve frames shall be circular, about 20 cm (7.87 inches) in diameter, 6 cm (2.36 inches) high, and provided with a pan about 5 cm (1.97 inches) deep and a cover.

NO. 200 CEMENT SIEVE, 0.0029-INCH OPENING.

The No. 200 sieve should have 200 wires per inch and shall conform to the following specification of diameter of wire and size of mesh:

The diameter of the wires in the sieve should be 0.0021 inch and the average diameter of such wires as may be measured shall not be outside the limits 0.0019 to 0.0023 inch for either warp or shoot wires. The number of warp wires per whole inch, as measured at any point of the sieve, shall not be outside the limits 195 to 202 per inch and of the shoot wires 192 to 204 per inch. For any interval of 0.25 to 0.50 inch, in which the mesh may be measured, the mesh shall not be outside the limits 192 to 203 wires per inch for the warp wires and 190 to 205 wires per inch for the shoot wires.

It is evident from the foregoing that standard sieves may contain surprisingly large individual openings and still meet the specifications; and while users and manufacturers of sieves have known that all sieve openings are not uniform, they have perhaps failed to realize that a very large range in size of openings can exist under the specifications, and actually does exist in the best standard sieves. It is undoubtedly this variation in size of individual openings that contributes very largely to the differences in sieving values of standard sieves; and it is evident that the relatively large openings in particular must have an effect on

[2] Circular No. 39, Bureau of Standards.

the sieving value, which can not be calculated or even closely estimated from any readily applied system of averages.

It therefore appears that the specifications for standard sieves, which should be primarily for the benefit of the user, are not adequately serving their purpose, and it is felt that a revision thereof should now be made on the basis of the investigation reported herewith. The specifications have, however, improved the quality of sieves, as shown by tests of old and of new ones.

Opportunity is here taken to thank the many testing laboratories for their cooperation and to acknowledge the assistance of the weights and measures and the photometric divisions of the Bureau. Special acknowledgment is also due of the careful work done by Mr. W. H. Sligh and Mr. D. W. Kessler in connection with the sieving tests.

II. SCOPE OF INVESTIGATION

This paper discusses the results of a number of observations made to determine methods of standardizing the 200-mesh sieve and its manipulation, so that greater uniformity may be obtained in its use. In the course of the investigation a study has been made of the following:

1. The accuracy of sieving tests, personal equation in sieving, variations in sieving values of standard sieves, and precautions necessary in sieving tests.
2. The results of sieving tests made in 85 different laboratories and a comparison of these results with those obtained by the Bureau of Standards on some of the same sieves.
3. Four proposed methods of standardizing sieves.
4. The suitability of a number of finely ground materials, as compared with Portland cement, for use in calibrating sieves.
5. The adoption of a standard value of fineness.
6. The application of a "correction" to the sieving value of standard sieves.
7. A revised specification for standard sieves.

III. SIEVING TESTS v. SIEVE MEASUREMENTS AS A BASIS OF CERTIFICATION FOR STANDARD SIEVES

1. UNIFORMITY OF RESULTS OF SIEVING TESTS AND PERSONAL EQUATION IN SIEVING

A choice between methods of standardizing cement sieves should be made on the basis of suitability and accuracy. The purpose of this discussion is to show that on the basis of accuracy, that is, on the basis of uniformity in the results which are being sought, sieving tests are preferable to microscopic calibration of the sieve cloth as a method of standardization.

In determining the sieving values of about 75 standard sieves with a specially prepared sample of cement, a maximum range in these values has been verified of slightly more than 4 per cent. A larger range has been found in the results of similar tests made in other laboratories, and it is probably safe to assume that certified standard sieves may vary 5 per cent in their sieving values.

The general accuracy of the sieving tests which have made up the greater part of this investigation is shown in Table 1. This table contains the variations from the average sieving values in 40 fineness determinations obtained by three operators, each making independent tests with samples of carefully mixed cement. In all these tests conditions were directly comparable, and all the results are tabulated. It is the practice of the Bureau in making these determinations to compare the three independent results thus obtained and to consider these satisfactory if the range is not appreciably greater than 0.5 per cent. If the range is greater than this amount, a retest is made by the operator whose result is most at variance with the others, and sometimes two or even three retests are made. All results obtained on any one sieve, however, are averaged in determining the sieving value of that sieve.

The results presented in Table 1 show that a single fineness determination by a competent operator should not be more than 0.5 per cent in error and is generally much closer than this, as indicated by the average variations of 0.12, 0.15, and 0.16 per cent, respectively.

61649°—14——2

TABLE 1

[Showing the Percentage Variations of Three Operators and the Range of Values obtained in 40 Fineness Determinations; 23 different Sieves were Used in these Tests]

Test No.	P	S	K	Range	Test No.	P	S	K	Range
1	+0.11	—0.19	+0.07	0.30	24	+ .01	— .07	+ .05	.12
2	— .10	+ .30	— .20	.50	25	+ .01	+ .15	— .15	.30
3	— .01	+ .21	— .19	.40	26	+ .01	— .07	+ .07	.14
4	— .23	+ .03	+ .21	.44	27	+ .11	— .25	+ .13	.38
5	— .20	+ .16	+ .04	.36	28	— .07	— .15	+ .21	.36
6	— .01	— .11	+ .13	.24	29	+ .20	— .38	— .18	.70
7	— .03	+ .01	+ .01	.04		+ .32	+ .04		
8	+ .13	— .13	— .01	.26	30	+ .02	— .36	+ .38	.74
9	— .13	+ .05	+ .07	.20			— .04		
10	+ .03	— .21	+ .17	.38	31	— .09	— .11	+ .19	.30
11	+ .16	— .32	+ .30	.62	32	— .04	— .20	+ .24	.44
		— .16			33	— .10	— .12	+ .22	.34
12	+ .03	— .15	+ .11	.26	34	— .11	— .15	+ .27	.42
13	— .02	+ .06	— .04	.10	35	— .01	— .19	+ .21	.40
14	— .34	— .06	+ .34	.68	36	+ .17	— .03	— .13	.30
			+ .04		37	+ .12	— .16	+ .04	.28
15	— .05	— .01	+ .05	.10	38	— .01	— .11	+ .13	.24
16	— .46	+ .04	+ .16	.92	39	+ .16	— .28	+ .12	.44
	— .22		+ .46		40	+ .16	— .26	+ .10	.42
17	— .16	+ .18	— .02	.34					
18	— .30	— .04	+ .30	.60	Highest	+ .32	+ .30	+ .46	.92
			+ .04		Lowest	— .46	— .38	— .20	.04
19	— .06	— .20	+ .26	.46	Algebraic				
20	— .04	— .20	+ .24	.44	average	— .03	— .10	+ .12	
21	— .01	— .19	+ .21	.40	Average,				
22	— .32	— .26	+ .28	.60	disregarding				
			+ .28						
23	— .05	— .17	+ .21	.38	sign	.12	.15	.16	.38

The algebraic average of each operator's variations shows his tendency to get higher or lower results than the others, and to this extent it represents his "personal" equation in sieving. These "personal equations" are remarkably small, in view of the fact that each of the three operators has developed well-defined peculiarities in sieving.

It is evident, therefore, that carefully made sieving tests of themselves involve far less uncertainty in the performance of a sieve than mere certification according to the present specifications. It is conceivable, however, that a very poor screen may have its imperfections so distributed that a fairly good sieving value will be obtained in tests similar to those described above but the graduation of the material passing through would not be comparable with that passing a uniformly woven screen. Such a sieve should be rejected irrespective of its sieving value, and in general it may be stated that satisfactory sieving tests without any other restriction whatever are not sufficient grounds for certification.

2. PRECAUTIONS NECESSARY IN SIEVING TESTS

It will be shown later that much larger variations in sieving values are reported from other laboratories than those given in Table 1. Therefore, it should be emphasized that a dependable sieving test requires care and patience on the part of the operator as well as strict attention to certain essential details of the operation.

The standard specifications for sieving [3] are as follows:

> The determination of fineness should be made on a 50-gram sample, which may be dried at a temperature of 100° C (212° F) prior to sifting. The coarsely screened sample (cement is ordinarily screened through a No. 20 sieve before mixing for routine test) should be weighed and placed on the No. 200 sieve, which, with the pan and cover attached, should be held in one hand in a slightly inclined position and moved forward and backward in the plane of inclination, at the same time striking the side gently about 200 times per minute against the palm of the other hand on the upstroke. The operation is to be continued until not more than 0.05 gram will pass through in one minute.

It is not necessary, however, that the entire sieving test be performed in this way, and a slight modification has been found to give more uniform results and to be far less fatiguing to the operator. The operation, as now carried out and recommended by the Bureau of Standards, is as follows:

Place the 50-gram sample on the 200 sieve with pan attached. Holding sieve and pan (without the cover) in both hands, sieve with a gentle wrist motion until most of the fine material has passed through, and the residue looks fairly clean. This operation usually requires only three or four minutes. Should there be any small lumps of fine material remaining, mash them up very gently against the screen with the ball of the forefinger, being careful to remove none of the coarser particles in this process.

When the residue appears clean, place the cover on the sieve, remove from pan, and, holding sieve and cover firmly in one hand, tap the side of the sieve gently with the handle of the brush used for cleaning the sieve (a three-fourths inch bristle brush with

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[3] United States Government Specification for Portland Cement, Circular 33, Bureau of Standards.

a 10-inch handle is a convenient size). Dust adhering to the sieve will thus be dislodged, and the underside of the screen may then be swept clean. Empty the pan and wipe out thoroughly with a cloth or waste. Replace the sieve in the pan and remove the cover carefully. If any of the coarser material has been caught in the cover during the tapping, see that it all gets back into the sieve.

The sieving may now be continued as before (with the cover removed) for 5 or 10 minutes, depending on the condition of the cement. The gentle wrist motion involves no danger of spilling the residue, the latter being kept well spread out on the screen, and the sieving is thus going forward much more easily and rapidly than when the specifications are followed throughout. More or less continuous rotation of the sieve is desirable throughout the operation. This open sieving may usually be continued safely for eight minutes or more, but care should be taken that it is not continued too long.

The cover should then be replaced and exactly the same process of cleaning followed as before. If the cement is in proper condition, there should now be no appreciable dust remaining in the residue nor adhering to sieve or pan.

The one-minute tests should now be made strictly according to specifications. It has been found, however, that 150 strokes per minute are equally as effective as 200 per minute and easier for the operator. Regular rotation of the sieve is essential, and the practice of sieving about 25 strokes in 10 seconds by the watch, then turning the sieve 60° and sieving for another 10 seconds, and so on throughout the one-minute tests, is conducive to uniform results. Sieves having covers with handles can be turned about the right amount without any trouble whatever, and flat covers may be marked with three straight lines through the center and intersecting at 60°. If one of the lines is marked with an arrowhead, and the habit is formed of starting this point under the right hand, one can easily keep track of the progress of the one-minute test. In the one-minute tests the sieve should be tapped rather than struck, for a gentle vibration of the screen is all that is required. Any considerable blow on the sieve will throw the residue against the cover and very likely result in the loss of material.

The essential points in the standard sieving operation may be summarized as follows:

1. Rotation of the sieve throughout the process, and particularly in the one-minute tests.

2. Guarding against loss of material. Most sieves are provided with covers which do not fit closely and are otherwise poorly made. If loss is suspected, sieve over white paper and always tap the sieve gently.

3. A good balance which may be relied upon to 1 or 2 milligrams is required. The ordinary cement laboratory balance, exposed to dust and rough usage, is not accurate enough for this work.

4. Washers, shot, and slugs should not be used on the sieve except in routine work—never in check tests nor in standardizing tests.

5. Avoid important tests on damp days. Excessive humidity interferes with good sieving. It tends to decrease the percentage of cement passing the sieve and, in general, to produce irregular results.

It has been suggested that the labor of making the sieve test might be considerably reduced by stopping the sieving when not more than 0.1 gram passes the sieve in one minute. While the difference in apparent fineness by this method as compared with present practice must be considerable, the relative uniformity obtained in the abbreviated method may not be inferior to that now obtained. Sufficient work has not been done to determine this, but it is being further investigated.

The use of a machine for making sieving tests has been advocated by many on the ground that a properly designed mechanical shaker should give more uniform results than can be obtained in hand sieving. It has been observed, however, that while a given machine may yield consistent results, different machines will give different results, sometimes considerably at variance with those obtained by hand. Therefore, however excellent may be the action of any one machine, unless this machine be universally adopted as a standard, it must eventually be checked by hand sieving. Difficulties also arise in connection with cleaning the sieves and making the one-minute tests; and it is doubtful if a machine can be very advantageously employed in standardizing work unless the number of sieves to be tested is large.

IV. COOPERATIVE SIEVING TESTS

1. VARIATION IN SIEVING VALUES OF STANDARD SIEVES AS DETERMINED BY THE BUREAU OF STANDARDS AND OTHER LABORATORIES

Under date of January 28, 1914, a circular letter was sent to practically all the cement-testing laboratories in the United States, requesting those who possessed 200-mesh sieves which had previously been certified by the Bureau of Standards to cooperate in determining the sieving values of these sieves on standard samples of cement furnished by the Bureau. The purpose of these tests was, first, to establish a definite standard of fineness and, second, to determine the approximate "corrections" to sieves based on this standard. A sufficient amount of cement was sent to the owners of the certified sieves for three tests on each sieve. Those participating in the investigation were asked to submit individual results of the tests, in order that the uniformity which was being obtained might be compared with that obtained by the Bureau.

Following is a list of the laboratories participating in the cooperative investigation:

Allentown Testing Laboratory, Allentown, Pa.
Alpha Portland Cement Co., Easton, Pa.
American Bureau of Inspection and Tests, Chicago, Ill.
Armour Institute of Technology, Chicago, Ill.
Ash Grove Lime & Portland Cement Co., Kansas City, Mo.
Atlas Portland Cement Co., Northampton, Pa.
Atchison, Topeka & Santa Fe Ry., Topeka, Kans.
Baltimore & Ohio R. R. Co., Baltimore, Md.
Bureau of Standards, Washington, D. C.; Pittsburgh, Pa.; Northampton, Pa.
California Portland Cement Co., Colton, Cal.
Cape Girardeau Cement Co., Cape Girardeau, Mo.
Chicago, Milwaukee & St. Paul R. R. Co., Chicago, Ill.
Chicago Portland Cement Co., Oglesby, Ill.
Colorado Portland Cement Co., Denver, Colo.
Coplay Portland Cement Co., Coplay, Pa.
Crescent Portland Cement Co., Wampum, Pa.
Dewey Portland Cement Co., Dewey, Okla.
Dexter Portland Cement Co., Nazareth, Pa.
District of Columbia Testing Laboratory, Washington, D. C.
Dixie Portland Cement Co., Richard City, Tenn.
Eastern Testing Laboratories, Allentown, Pa.
Erie R. R. Co., Jersey City, N. J.
Fredonia Portland Cement Co., Fredonia, Kans.
German-American Portland Cement Co., La Salle, Ill.
Glens Falls Portland Cement Co., Glens Falls, N. Y.

Giant Portland Cement Co., Philadelphia, Pa.
Gulick-Henderson Co., Pittsburgh, Pa.
Hunt Co., Robt. W., Chicago, Ill.; Pittsburgh, Pa.; New York, N. Y.; St. Louis, Mo.; Seattle, Wash.; San Francisco, Cal.; Los Angeles, Cal.; Vancouver, British Columbia.
Huron Portland Cement Co., Alpena, Mich.
Inland Portland Cement Co., Metaline Falls, Wash.
Iola Portland Cement Co., Iola, Kans.
Iowa Portland Cement Co., Des Moines, Iowa.
Iowa State College, Ames, Iowa.
Michigan Portland Cement Co., Chelsea, Mich.
Millen Co., Thos., Jamesville, N. Y.
New Castle Portland Cement Co., New Castle, Pa.
New York Public Service Commission, New York, N. Y.
New York State Commission of Highways, Albany, N. Y.
New York State Engineering Department, Albany, N. Y.
Odgen Portland Cement Co., Brigham City, Utah.
Oklahoma Portland Cement Co., Ada, Okla.
Olympic Portland Cement Co., Bellingham, Wash.
Penn-Allen Portland Cement Co., Nazareth, Pa.
Pennsylvania Cement Co., Nazareth, Pa.
Pittsburgh Testing Laboratory, Pittsburgh, Pa.; Easton, Pa.; Dallas, Tex.
Riverside Portland Cement Co., Riverside, Cal.
Sandusky Portland Cement Co., Sandusky, Ohio.
Santa Cruz Portland Cement Co., Davenport, Cal.
Smith Emery & Co., San Francisco, Cal.
Southern States Portland Cement Co., Rockmart, Ga.
Southwestern States Portland Cement Co., El Paso, Tex.
Standard Portland Cement Co., Leeds, Ala.
Three Forks Portland Cement Co., Trident, Mont.
Tidewater Portland Cement Co., Union Bridge, Md.
Union Portland Cement Co., Devils Slide, Utah.
Union Sand & Materials Co., St. Louis, Mo.
United States Engineer Office, Cincinnati, Ohio.
United States Reclamation Service, Denver, Colo.; San Francisco, Cal.; Elephant Butte, N. Mex.
Universal Portland Cement Co., Chicago, Ill.
University of California, Berkeley, Cal.
University of Wisconsin, Madison, Wis.
Vulcanite Portland Cement Co., Philadelphia, Pa.
Washington Filtration Plant, Washington, D. C.
Washington Portland Cement Co., Concrete, Wash.
Western States Portland Cement Co., Independence, Kans.
Wolverine Portland Cement Co., Quincy, Mich.
Wyandotte Portland Cement Co., Wyandotte, Mich.

Of the 254 standard 200-mesh sieves which had been certified by the Bureau up to July 1, 1914, 162 were tested with the standard sample of cement; 16 others were located, but the results of the tests were not received. The results obtained are given in Tables 2 and 3.

TABLE 2

Results of Sieving Tests Made by Various Laboratories on a Standard Sample of Cement Furnished by the Bureau of Standards

[a=1 determination, b=2 determinations, c=4 determinations, d=5 determinations, e=6 determinations. No. 716 was dried below 250° F.]

Sieve marked B. S. No.—	Per cent passing 200 mesh	Range of three or more determinations	Variation from standard value of 77 per cent	Sieve marked B. S. No.—	Per cent passing 200 mesh	Range of three or more determinations	Variation from standard value of 77 per cent
4	76.50	0.62	−0.50	241	78.58	0.06	+1.58
5	76.45	.30	− .55	318	77.20	1.30	+ .20
6	76.68	.50	− .32	320	77.70	.28	+ .70
7	76.65	.40	− .35	332	78.65	.10	+1.65
9	77.47	.40	+ .47	345	79.02	.05	+2.02
10	76.67	.10	− .33	346	86.60	.40	+9.60
11	77.83	.20	+ .83	346	76.70b	.20b	− .30
12	77.21	.40	+ .21	365	76.47	.60	− .53
13	78.20a	....	+1.20	371	78.07	.20	+1.07
14	77.55	.82	+ .55	372	79.80	.40	+2.80
16	77.19	.09	+ .19	373	78.93	.20	+1.93
46	79.55	1.07	+2.55	374	79.23	.10	+2.23
46	79.55	.41	+2.55	375	79.11	1.04	+2.11
47	77.80a	....	+ .80	375	79.01	.10	+2.01
48	79.33	.10	+2.33	382	76.23	.08	− .77
49	78.07	.10	+1.07	408	79.53	.38	+2.53
51	78.00a	....	+1.00	409	78.50a	....	+1.50
52	76.80a	....	− .20	410	80.07b	.04b	+3.07
52	77.00a	....	.00	411	77.69	.25	+ .69
53	77.00a	....	.00	415	77.75	.12	+ .75
53	76.80a	....	− .20	416	77.43	.78	+ .43
54	77.00a	....	.00	416	77.47	.13	+ .47
54	77.00a	....	.00	418	77.47	.20	+ .47
66	79.71c	.03c	+2.71	419	76.93	.10	− .07
67	77.37	.50	+ .37	427	77.87	.10	+ .87
67	77.10	1.00	+ .10	429	77.53	.20	+ .53
68	76.06	.33	− .94	430	79.08b	.04b	+2.08
69	78.60b	.00b	+1.60	431	76.93	.20	− .07
75	78.70c	.70c	+1.70	432	78.00	.00	+1.00
76	77.57	.21	+ .57	433	73.80a	....	−3.20
78	77.09	.25	+ .09	434	76.49	1.08	− .51
80	76.44a	....	− .56	434	76.84	.25	− .16
142	77.84	.46	+ .84	435	78.45	.18	+1.45
145	76.84	.44	− .16	436	76.07	.10	− .93
146	76.83	.40	− .17	437	74.77	.52	−2.23

TABLE 2—Continued

Results of Sieving Tests Made by Various Laboratories on a Standard Sample of Cement Furnished by the Bureau of Standards—Continued

[a=1 determination, b=2 determinations, c=4 determinations, d=5 determinations, e=6 determinations. No. 716 was dried below 250° F.]

Sieve marked B. S. No.—	Per cent passing 200 mesh	Range of three or more determinations	Variation from standard value of 77 per cent	Sieve marked B. S. No.—	Per cent passing 200 mesh	Range of three or more determinations	Variation from standard value of 77 per cent
438	76.93	0.40	−0.07	623	78.14	1.04	+1.14
439	75.87	.20	−1.13	624	77.24	.20	+ .24
440	77.83	.30	+ .83	627	77.54	.48	+ .54
441	77.67	.30	+ .67	676	77.73	.02	+ .73
471	78.57	.78	+1.57	678	78.43	.30	+1.43
472	79.39c	.12c	+2.39	679	76.83	.30	− .17
474	78.67	.20	+1.67	680	79.37	.14	+2.37
475	78.58	.16	+1.58	685	79.48b	.28b	+2.48
476	78.26	1.41	+1.26	686	76.47	1.00	− .53
480	78.72	.22	+1.72	687	78.85	.06	+1.85
493	80.60	.00	+3.60	690	78.24	.12	+1.24
493	77.80	.40	+ .80	691	77.27	.80	+ .27
496	77.86b	.07b	+ .86	692	77.20	.20	+ .20
498	76.90b	.20b	− .10	694	77.22	.36	+ .22
499	76.54a	....	− .46	695	76.68	.38	− .32
499	77.79	1.14	+ .79	709	79.58b	.08b	+2.58
529	76.27	.20	− .73	710	78.54	.10	+1.54
530	77.67	1.20	+ .67	712	78.66	.18	+1.66
576	76.41d	.42d	− .59	713	80.00a	....	+3.00
587	78.72	.23	+1.72	714	78.41	.46	+1.41
589	75.33	.20	−1.67	714	78.54	.18	+1.54
590	75.07	.40	−1.93	715	76.90	.40	− .10
591	73.60a	....	−3.40	716	75.44	.39	−1.56
592	76.57	.10	− .43	720	77.03	.10	+ .03
593	76.20b	.30b	− .80	721	77.17	.30	+ .17
611	75.87	.20	−1.13	722	76.23	.30	− .77
615	77.36	.82	+ .36	723	77.13	.20	+ .13
615	77.35	.15	+ .35	730	77.47	.30	+ .47
616	78.53a	....	+1.53	731	78.73	.10	+1.73
616	75.95	.25	−1.05	732	77.53	.10	+ .53
617	79.00a	....	+2.00	733	76.44b	.35b	− .56
617	75.59	.30	−1.41	734	77.68	.42b	+ .68
619	77.80b	.00b	+ .80	737	77.40a	....	+ .40
620	77.03	.10	+ .03	739	77.00a	....	.00
622	76.36	.36	− .64	739	77.20a	....	+ .20

The results reported in Table 2 were obtained by the laboratories owning the sieves. The results show a range of not more than 1 per cent for three or more determinations in any one laboratory, excepting in eight cases. The maximum variation from the finally adopted standard of 77 per cent for all laboratories was 9.60 per cent, but retests in a number of cases indicated that practically all determinations showing a variation of more than 3 per cent from the standard were unreliable. Thus retests on sieves Nos. 346, 433, 437, 493, 590, and 591 showed that the first results obtained on these sieves were considerably in error. Disregarding these results, the highest value reported is 80.07 per cent on sieve No. 410, and the lowest is 75.33 per cent on sieve No. 589, showing a maximum range of 4.74 per cent.

The results reported in Table 3 are from tests that have been made at the Bureau on 38 new sieves submitted by the manufacturers for certification. The total range of sieving values obtained is only 1.44 per cent and testifies to a decided improvement in manufacture of the more recent sieves.

TABLE 3

Results of Sieving Tests Made at the Bureau of Standards on the Standard Sample of Cement Furnished to Other Laboratories

[c=4 determinations, d=5 determinations, e=6 determinations.]

Sieve marked B. S. No—	Per cent passing 200 sieve	Range of three determinations	Variation from standard value of 77 per cent	Sieve marked B. S. No—	Per cent passing 200 sieve	Range of three determinations	Variation from standard value of 77 per cent
70	77.12	0.04	+0.12	93	78.29d	0.66d	+1.29
71	77.94	.24	+ .94	94	77.49	.42	+ .49
72	77.25	.10	+ .25	121	77.73	.22	+ .73
73	77.61	.22	+ .61	122	78.03	.12	+1.03
74	77.94	.28	+ .94	124	77.27	.16	+ .27
77	77.24	.10	+ .24	125	77.65d	1.00d	+ .65
79	77.09d	.70d	+ .09	126	77.41d	.64d	+ .41
81	77.72d	.70d	+ .72	127	78.23	.30	+1.23
82	77.76d	.90d	+ .76	128	77.35	.40	+ .35
83	78.11	.72	+1.11	129	76.91c	.64c	— .09
84	78.23	.26	+1.23	130	77.33	.52	+ .33
85	77.49	.46	+ .49	132	78.35	.46	+1.35
86	77.76e	.52e	+ .76	133	77.72c	.62c	+ .72
87	78.30	.26	+1.30	134	76.97	.40	— .03
88	78.25	.22	+1.25	136	77.56c	.62c	+ .56
89	77.36c	.62c	+ .36	137	77.30c	.68c	+ .30
90	77.17d	.58d	+ .17	138	77.75	.10	+ .75
91	77.75c	.54c	+ .75	139	77.68	.34	+ .68
92	77.97	.50	+ .97	140	77.32c	.60c	+ .32

2. COMPARISON OF SIEVING VALUES OBTAINED BY THE BUREAU OF STANDARDS AND OTHER LABORATORIES ON THE SAME SIEVES

In a number of cases the results reported in Table 2 showed unexpected variations, and an endeavor was therefore made to get as many comparisons as possible between results obtained on the same sieves in the Bureau and in other laboratories. A number of privately owned sieves were submitted for this purpose on request, and a number of others were purchased after tests had been made by the Bureau and were subsequently retested by the owner.

Table 4 contains the results of sieving tests made by the Bureau and other laboratories on the same sieves. The last column shows that in about one-half of the cases where check determinations were made differences of over 1 per cent were obtained. These variations would be rather discouraging were it not for the fact that several of them were obtained from check tests on questionable determinations, and there is no reason to believe that the average discrepancy between the Bureau's results and those of other laboratories is nearly as large as the average of those in Table 4. Nevertheless, these comparisons show that considerable errors may occur when the sieving tests are made carelessly or without due regard to all directions. Since in very many cases it is not possible to know whether the tests have been properly made, it has not been deemed advisable to base a standard on the results obtained from the cooperative tests. The reasons for the adoption of a value of 77 per cent as the fineness of the standard sample submitted are given in a later paragraph, but it may be pointed out that the approximate "corrections" to the tested sieves (which are obviously the values given in the last column of Table 2 with the opposite sign) are approximate only to the degree of excellence of the sieving tests on which they are based. Each operator must decide for himself whether his personal error is sufficient to affect the reliability of the "correction factor" which he has determined by his tests.

TABLE 4

Comparison of Results of Sieving Tests Made by the Bureau of Standards and Various Laboratories on a Standard Sample of Cement Furnished by the Bureau of Standards

Sieve marked No.	Bureau of Standards	Outside laboratories	Variation from Bureau of Standards determinations	Sieve marked No.	Bureau of Standards	Outside laboratories	Variation from Bureau of Standards determinations
51	77.93	78.00	+0.07	80	77.62	76.44	—1.18
66	79.03	79.71	+ .68	433	77.93	73.80	—4.13
	79.11	....	+ .60	437	76.57	74.77	—1.80
67	78.63	77.37	—1.26	499	76.75	76.54	— .21
		77.10	—1.53			77.79	+1.04
68	76.86	76.06	— .80	590	75.69	75.07	— .62
69	77.33	78.60	+1.27	591	75.51	73.60	—1.91
75	77.45	78.70	+1.25	623	77.79	78.14	+ .35
76	78.61	77.57	—1.04	624	76.95	77.24	+ .29
78	77.32	77.09	— .23	710	78.35	78.54	+ .19

V. A COMPARISON OF METHODS OF TESTING SIEVES

Since the real purpose of standardizing cement sieves is to insure their correctness and uniformity, the criterion for any method of standardizing is the reliability with which the results may be interpreted in terms of sieving values. This discussion is devoted to a comparison of results of three methods which have been used or which have been proposed for testing sieves.

1. RELATION BETWEEN SIEVE MEASUREMENTS AND SIEVING VALUES AND VARIATIONS IN SIEVE OPENINGS

The present method of certification of a sieve consists in determining (1) the average diameter of the wires, (2) the average number of meshes per linear inch, (3) the maximum and minimum number of meshes per whole inch interval, and (4) the maximum and minimum number of meshes per quarter-inch interval.

The maximum variations which are permitted in sieves which meet the specifications are given on page 5.

Table 5 contains the data taken from the certificates of 43 standard sieves, together with their sieving values as determined in the Bureau's laboratory on the cement used in the cooperative tests. The most obvious relation between the observed sieving values and the other measurements appears to be in the wire diameters—that is, the smaller the wires the more open the sieves. Thus, sieves 67 and 84 have the smallest average wire diameters and high sieving values, while sieves 4, 6, 437, 499, and 591 have the largest average wire diameters and low sieving values.

It might be presumed that the most uniform sieves would be those which come nearest to the ideal sieves as indicated by the certification measurements; for example, let us select those sieves of which the average wire diameters are not outside the limits 0.00205 inch to 0.00215 inch, the average meshes per linear inch are not outside the limits 199 to 201 and the average meshes in quarter-inch intervals for either warp or shoot are not outside the limits 196 to 204. (These limits are about as close as it is possible to have them and not exclude all the sieves; thus, if the quarter-inch limits were made 197 and 203, no sieve in this list would meet these requirements.) The parentheses indicate the sieves which are within these limits. It is seen that the sieving values of these selected sieves range from 76.36 per cent to 78.30 per cent, and while this may be considered quite satisfactory, there are no less than 23 of the presumably inferior sieves which have sieving values also within these limits. Moreover, the average sieving value of the 15 selected sieves is 77.48 per cent, while that of the other 23 is 77.35 per cent; that is, a better average sieving value than that of the selected sieves. Without attempting to further analyze the data in Table 5, it is quite evident that the certification measurements as made heretofore do not justify a very reliable deduction as to sieving values, and indicate only a general tendency toward openness or closeness in the sieves. The data show, however, that as the sieves are now being made, the dimensions are for the most part well within the tolerances of the bureau specifications, and that the average wire diameter and mesh of the sieves is usually very close to the nominal values .0021 inch and 200 meshes per inch, respectively.

As already stated in the introduction, it is believed that the variation in sieving values of sieves is due largely to the variations in the individual openings. That these openings are quite irregular in all grades of 200-mesh sieves is shown in Table 6.

TABLE 5

Results of Measurements and Relative Sieving Values of 200-Mesh Standard Sieves

Sieve No.	Average diameter of wires, ten-thousandths inch		Average number of meshes per linear inch		Range in number of wires per linear inch								Fineness of standard sample as determined by sieving test	Variation from standard value of 77 per cent
					In whole-inch intervals				In quarter-inch intervals					
					Warp wires		Shoot wires		Warp wires		Shoot wires			
	Warp	Shoot	Warp	Shoot	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.		
4	23	22	200	197	199	200	193	204	197	202	190	205	76.50	− 0.50
5	22	22	200	197	199	200	194	198	196	203	192	200	76.45	− .55
6	23	22	200	195	199	200	193	196	198	203	192	198	76.68	− .32
7	22	22	200	197	200	200	194	200	196	202	193	204	76.65	− .35
51	20	20	199	197	198	202	196	198	196	203	196	198	77.93	+ .93
66	20	20	198	194	197	199	193	195	196	202	192	197	79.11	+ 2.11
67	19	20	198	199	198	199	196	203	196	200	195	204	78.63	+ 1.63
(68)	(21)	(22)	(200)	(201)	(199)	(201)	(199)	(203)	(198)	(202)	(198)	(204)	(76.86)	−(0.14)
(69)	(21)	(22)	(200)	(200)	(199)	(201)	(197)	(202)	(196)	(203)	(196)	(204)	(77.33)	+(0.33)
70	22	22	199	201	197	200	199	202	196	202	198	205	77.12	+ .12
(71)	(21)	(21)	(199)	(199)	(198)	(200)	(198)	(200)	(196)	(201)	(197)	(203)	(77.94)	+(0.94)
72	22	22	200	200	198	201	198	202	197	203	196	203	77.25	+ .25
73	22	22	200	200	199	200	196	202	196	203	191	204	77.61	+ .61
(74)	(22)	(21)	(201)	(199)	(199)	(202)	(198)	(201)	(198)	(202)	(196)	(202)	(77.94)	+(0.94)
75	22	22	199	200	197	201	199	202	196	203	197	202	77.45	+ .45
76	20	20	198	198	198	199	197	200	196	200	195	201	78.61	+ 1.61
77	22	22	201	200	200	202	198	202	197	203	197	204	77.24	+ .24
(78)	(21)	(21)	(201)	(201)	(199)	(202)	(199)	(203)	(197)	(203)	(198)	(204)	(77.32)	+(0.32)
(79)	(21)	(21)	(200)	(200)	(199)	(202)	(197)	(202)	(197)	(203)	(196)	(204)	(77.09)	+(0.09)
80	22	21	199	200	197	200	195	202	196	202	192	204	77.62	+ .62
(81)	(22)	(21)	(201)	(200)	(199)	(202)	(198)	(202)	(198)	(203)	(196)	(204)	(77.72)	+(0.72)
(82)	(22)	(20)	(199)	(200)	(198)	(201)	(197)	(201)	(196)	(202)	(196)	(202)	(77.76)	+(0.76)

83	22	20	200	199	198	201	196	201	194	203	194	202	78.11	+ 1.11
84	20	19	197	199	196	198	196	203	196	198	194	205	78.23	+ 1.23
(85)	(22)	(21)	(200)	(199)	(199)	(201)	(197)	(201)	(197)	(202)	(196)	(203)	(77.49)	+(0.49)
86	22	21	201	200	199	202	197	202	197	203	195	204	77.76	+ .76
(87)	(22)	(21)	(199)	(199)	(198)	(200)	(197)	(201)	(196)	(203)	(196)	(202)	(78.30)	+(1.30)
88	22	19	201	199	200	202	196	200	197	203	194	202	78.25	+ 1.25
89	21	20	200	200	199	201	197	201	197	203	195	203	77.36	+ .36
(90)	(22)	(21)	(200)	(200)	(199)	(200)	(198)	(202)	(197)	(202)	(196)	(203)	(77.17)	+(0.17)
(91)	(21)	(20)	(199)	(200)	(198)	(200)	(198)	(201)	(196)	(203)	(196)	(203)	(77.75)	+(0.75)
92	21	20	201	199	200	202	196	201	196	203	193	203	77.97	+ .97
(93)	(21)	(20)	(199)	(199)	(198)	(201)	(197)	(201)	(197)	(203)	(196)	(202)	(78.29)	+(1.29)
94	21	20	200	200	200	201	196	203	197	202	195	204	77.49	+ .49
433	22	22	198	199	197	200	196	201	195	202	195	204	77.93	+ .93
437	23	22	200	197	200	201	195	199	197	203	194	201	76.57	− .43
499	23	22	200	201	199	201	200	203	196	203	198	204	76.75	− .25
576	22	22	200	199	199	200	197	202	197	200	194	203	76.41	− .59
591	23	22	198	196	196	200	194	197	194	202	192	200	75.51	− 1.49
(622)	(21)	(21)	(199)	(200)	(199)	(200)	(197)	(202)	(196)	(202)	(196)	(204)	(76.36)	−(0.64)
623	21	20	199	197	198	201	194	201	195	204	192	202	77.79	+ .79
(624)	(20)	(21)	(199)	(200)	(198)	(200)	(198)	(202)	(196)	(202)	(196)	(204)	(76.95)	−(0.05)
710	21	21	198	200	198	199	198	203	196	201	197	204	78.35	+ 1.35

This table shows the variations in size of two sets of 10 consecutive openings in both warp and shoot wires as measured on four sieves of widely varying sieving values. The places selected for measurement were not necessarily the worst places on the sieves, but were taken where the variation was seen to be considerable after a brief inspection under the microscope.

The results on these four sieves serve as another illustration of the inadequacy of the present specifications, for according to this method of certification sieves 294 and X fail to meet the requirements, whereas 576 and 66 now bear the Bureau of Standards seal. Sieving tests would indicate that 576 and X are the better sieves.

The most striking conclusion that may be drawn from the measurements recorded in Table 6 is that the warp wires are spaced very much more irregularly than the shoot wires. In fact, the microscope is not needed to show up the imperfections of the warp, as the latter can always be distinguished by the naked eye, by simply holding the sieve up to the light and noting the bands of light and shadow produced by the unevenness in the spacing of the warp wires, whereas the shoot wires appear more uniform and are without distinct bands. Over an interval as large as a quarter inch, however, which is the minimum interval considered in the specifications, the *average* mesh of the warp wires is usually nearer the nominal mesh of 200 per inch than is that of the shoot wires. Just why the individual openings of the shoot wires should be invariably more uniform than those of the warp is not plain, when it is remembered that the latter are spaced mechanically while the former are driven in by hand. This irregularity in spacing of the warp wires should be subject to improvement by the manufacturer, but we are not able at the present time to suggest a reasonable modification of the specification which will improve the cloth in this respect.

Figs. 1 and 2 show some of the imperfections and irregular spacing of the wires in two of the best standard sieves in the Bureau laboratory. The broken and loose wires are, of course, only local defects, whereas the irregular spacing extends across the sieve. The magnification in these photographs is such that if the entire sieve were shown on the same scale, it would cover a circular area 30 feet or more in diameter.

TABLE 6

Comparison of Measured Openings and Sieving Values of Four 200-Mesh Sieves

Sieve marked—	No.	Openings between warp wires (inch)		Openings between shoot wires (inch)		Warp openings		Shoot openings		Sieving value
						Maximum	Minimum	Maximum	Minimum	
	1	0.0024	0.0032	0.0029	0.0027					
	2	26	33	28	29					
	3	31	30	30	31					
	4	49	33	25	29					
294	5	26	28	30	30	0.0049	0.0024	0.0039	0.0025	74.5
	6	28	34	39	28					
	7	29	26	38	29					
	8	28	24	26	33					
	9	25	34	29	27					
	10	24	24	25	29					
	1	.0034	.0029	.0031	.0025					
	2	39	24	29	30					
	3	28	25	29	29					
	4	27	36	30	31					
576	5	25	26	28	29	.0041	.0019	.0031	.0025	76.4
	6	23	25	28	30					
	7	36	26	28	26					
	8	27	24	27	30					
	9	31	41	27	28					
	10	25	19	29	29					
	1	.0042	.0030	.0032	.0030					
	2	29	28	31	31					
	3	29	41	31	32					
	4	20	25	27	32					
X	5	32	25	31	32	.0044	.0020	.0036	.0027	77.5
	6	33	27	32	33					
	7	30	30	29	29					
	8	30	24	27	27					
	9	29	23	28	29					
	10	44	35	31	36					
	1	.0029	.0026	.0027	.0030					
	2	36	51	29	30					
	3	26	25	27	29					
	4	30	24	29	34					
66	5	32	32	31	30	.0051	.0022	.0039	.0027	79.1
	6	22	30	38	30					
	7	25	24	39	31					
	8	38	23	32	29					
	9	24	38	28	30					
	10	24	34	29	29					

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In this connection it is interesting to refer to an article by G. J. Griesenauer [4] on "A Sieve Test for Cement that Insures Uniformity in Fineness." In this paper the author called attention to the fact that by holding a sieve in such manner that the cement always passed back and forth across the warp wires, a higher percentage passing the sieve was invariably obtained than when the test was made by sieving across the shoot wires. A number of tests were made at the Bureau of Standards which in a general way confirmed Mr. Griesenauer's results, although the differences observed were less, and no greater uniformity was obtained than in the usual method of rotating the sieve. The invariable lack of uniformity in the spacing of the warp, however, suggests the explanation for a higher sieving value across the warp wires, for it is evident that if the cement is moving in the lengthwise direction of the large openings the particles are more likely to pass through these openings than when moving across them. Furthermore the greater bending of the warp wires produces in effect a rougher surface across the warp than across the shoot, and the particles are thus "pocketed" in this direction more readily than when moving across the shoot.

The tests performed by Mr. Griesenauer are therefore additional evidence that the variations in sieving values are closely related to the imperfections in the spacing of the warp wires.

2. A PROPOSED OPTICAL TEST OF SIEVES AND ITS RELATION TO THE SIEVING VALUES

Inability to interprct the usual certification measurements of sieves in terms of sieving values led to a search for some method of standardization, from the results of which might be drawn a satisfactory inference with regard to sieving values, thus avoiding the very considerable labor of making the actual sieving tests. Unfortunately the optical method proposed and tried out was found to be inadequate, but a brief description of the test is here given.

[4] A sieve test for cement that insures uniformity in fineness, Engineering News, 70, p. 1296, Dec. 25, 1913.

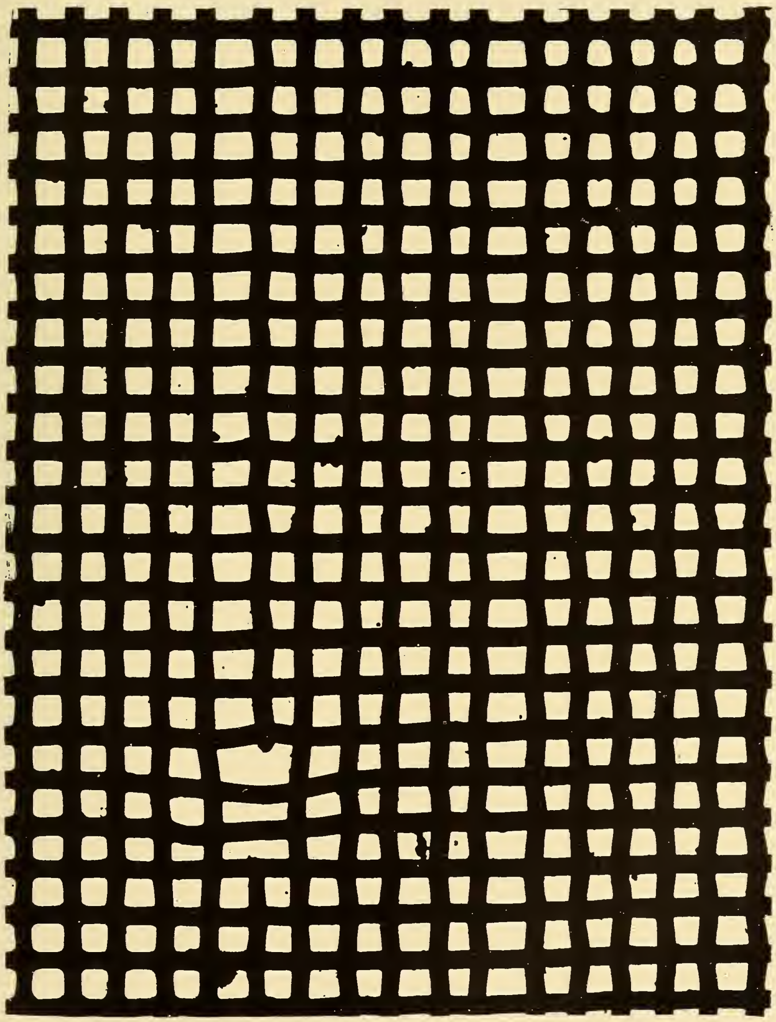

FIG. 1.—*Showing broken wire, nonuniform spacing of warp wires, and irregularities in size and shape of openings in a standard No. 200 sieve. (Warp wires vertical.) Magnification, 50 diameters*

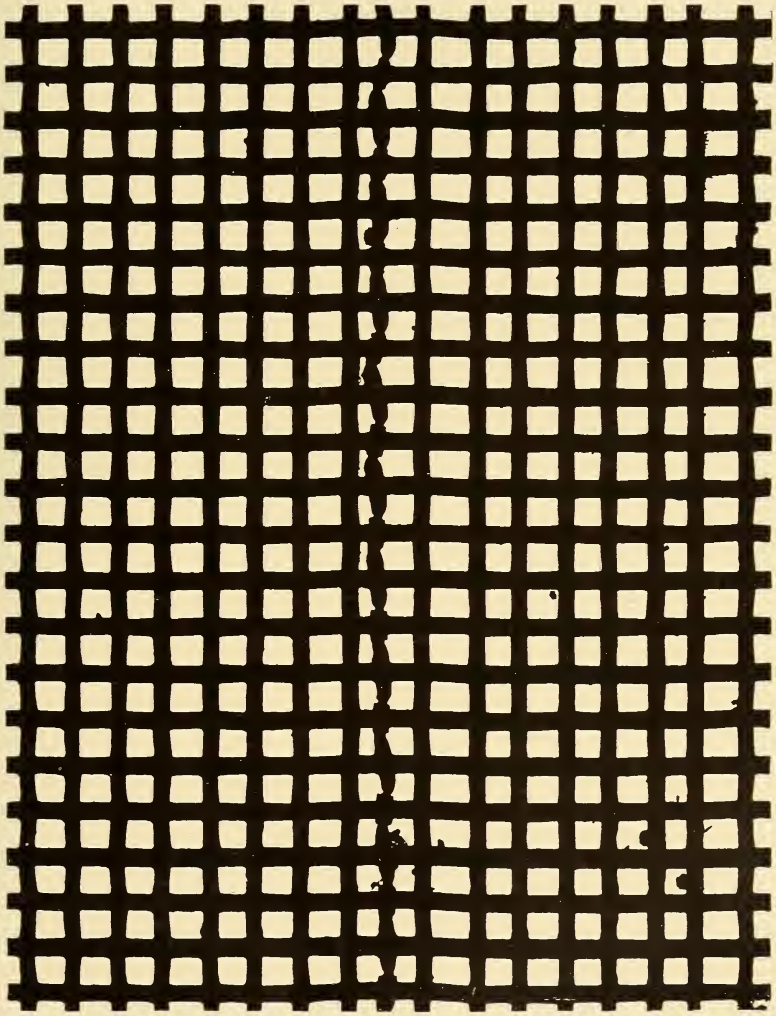

FIG. 2.—*Showing defective warp wire and irregular openings in a standard No. 200 sieve. (Warp wires vertical.) Magnification, 50 diameters*

The Bureau possesses facilities for making various kinds of photometric tests, and it was believed that the amount of light passed by different sieves could be thus determined and might bear some relation to their sieving values. Omitting details of the arrangement of the apparatus, it was found possible to get an approximate integral effect of the amount of light transmitted by a sieve, and the photometric measurements on the sieves subjected to the tests gave quite accurate determinations of the relative quantity of light transmitted by each.

Table 7 contains the results of the photometric tests on 29 sieves made by the photometric division of the Bureau. For convenience in comparing results the sieves are grouped in order of their sieving values and opposite each group is the mean of the photometric results on the sieves in that group. The light transmission is expressed as the ratio of the amount passed by the screen to that passed when the screen was removed. It is evident that although this method does indicate the general openness of a sieve under certain conditions it serves little if any better as an indicator of the sieving values than the present method of certification. It will be observed that all the intermediate sieves show appreciably the same light transmission irrespective of their sieving values. However, complete indications of the sieving values of sieves can not be obtained by this method, for it is readily seen that any screen containing a definite amount of wire would pass the same amount of light irrespective of the uniformity of weave, whereas the latter would have a very great effect on the sieving value.

The sieving values of the sieves listed in Table 7 show that the certification of sieves on the present basis is not satisfactory. It is observed that the range in sieving values of these 29 sieves is almost exactly the same as that of the 15 selected sieves in Table 5. In other words, all of these sieves show a performance of their real function, which is in no wise inferior to those of the best sieves obtainable under the specifications. Yet, as noted in the last column of Table 7, 12 of these sieves have been rejected.

TABLE 7

Comparison of Results of Photometric Tests and Sieving Tests on 29 200-Mesh Sieves

Sieve marked—	Sieving value	Light transmission	Average light transmission	Result of present certification tests
P	76.4	0.315	0.315	Rejected.
G	76.5	.319	.319	Do.
AA	76.9	.316		Do.
L (No. 129)	76.9	.317	.318	Standard.
O	76.9	.321		Rejected.
W	77.0	.315		Do.
T (No. 134)	77.0	.320	.318	Standard.
C	77.0	.318		Rejected.
U	77.2	.320	.320	Do.
E (No. 124)	77.3	.319		Standard.
Y (No. 137)	77.3	.318	.315	Do.
CC (No. 140)	77.3	.299		Do.
M (No. 130)	77.3	.325		Do.
K (No. 128)	77.4	.315		Do.
H (No. 126)	77.4	.322	.321	Do.
N	77.4	.325		Rejected.
D	77.5	.318	.318	Do.
X	77.5	.319		Do.
R	77.6	.322		Do.
V (No. 136)	77.6	.318	.318	Standard.
J	77.6	.311		Rejected.
F (No. 125)	77.6	.322		Standard.
BB (No. 139)	77.7	.317		Do.
S (No. 133)	77.7	.317	.318	Do.
A (No. 121)	77.7	.320		Do.
Z (No. 138)	77.8	.325	.325	Do.
B (No. 122)	78.0	.325	.325	Do.
I (No. 127)	78.2	.324	.324	Do.
Q (No. 132)	78.4	.363	.363	Do.

3. A SIEVE TEST BASED ON THE SIZE OF SEPARATION AND ITS RELATION TO THE SIEVING VALUE

The usual method of reporting the granulometric composition of sands is by means of curves whose abscissae are the average diameters of the sand particles and whose ordinates are the percentages of total material. Thus any point of such a curve indicates the quantity of sand particles in a given sample which are below the size represented by the abscissa of that point. Theoretically, this method is a logical one for determining the size of particle sieves of any size mesh will pass if the sieves are assumed to have openings of reasonably uniform size, and it has been suggested as a method of standardizing cement sieves. In the case of the 200-mesh sieve, however, where the mesh opening varies 50 per cent and more in size, the method is wholly inaccurate. Furthermore, when it is desired to compare many 200-mesh sieves with some definite standard, the difficulties involved in this method are such that it becomes impracticable.

This method appears to have been developed by Allen Hazen, and was described by him in a paper on "Some Physical Properties of Sands and Gravels" in the report of the Massachusetts State Board of Health for 1892. While the method has no doubt served excellently the purpose for which it was intended, it is based on certain assumptions which do not hold good in the intercomparison of very fine sieves, although justified for the comparison of the coarser sieves. The point in question may be best brought out by a quotation from the paper referred to.[5]

It can be easily shown by experiment that when a mixed sand is shaken upon a sieve the smaller particles pass first, and as the shaking is continued larger and larger particles pass, until the limit is reached when almost nothing will pass. The last and largest particles passing are collected and measured, and they represent the separation of that sieve. The size of separation of a sieve bears a tolerably definite relation to the size of the mesh, but the relation is not to be depended upon, owing to the irregularities in the meshes and also to the fact that the finer sieves are woven on a different pattern from the coarser ones, and the particles passing the finer sieves are somewhat larger in proportion to the mesh than is the case with the coarser sieves. For these reasons the sizes of the sand grains are determined by actual measurements, regardless of the size of the mesh of the sieve.

DETERMINATION OF THE SIZES OF THE SAND GRAINS.

The sizes of the sand grains can be determined in either of two ways, from the weight of the particles or from micrometer measurements. For convenience the size of each particle is considered to be the diameter of a sphere of equal volume. When the weight and specific gravity of a particle are known, the diameter can be readily calculated. The volume of a sphere is $\frac{1}{6}\pi d^3$, and is also equal to the weight divided by the specific gravity. With the Lawrence materials the specific gravity is uniformly at 2.65 within very narrow limits, and we have $\frac{w}{2.65}=\frac{1}{6}\pi d^3$. Solving for d we obtain the formula $d=.9\sqrt[3]{w}$ when d is the diameter of a particle in millimeters and w its weight in milligrams. As the average weight of particles, when not too small, can be determined with precision, this method is very accurate, and altogether the most satisfactory for particles above 0.10 millimeter; that is, for all sieve separations. For the finer particles the method is inapplicable, on account of the vast number of

[5] Some Physical Properties of Sands and Gravels, by Allen Hazen. Twenty-fourth Annual Report of the State Board of Health of Massachusetts for 1892.

particles to be counted in the smallest portion which can be accurately weighed, and in these cases the sizes are determined by micrometer measurements. As the sand grains are not spherical or even regular in shape, considerable care is required to ascertain the true mean diameter. The most accurate method is to measure the long diameter and the middle diameter at right angles to it, as seen by a microscope. The short diameter is obtained by a micrometer screw, focusing first upon the glass upon which the particle rests and then upon the highest point to be found. The mean diameter is then the cube root of the product of the three observed diameters. The middle diameter is usually about equal to the mean diameter, and can generally be used for it, avoiding the troublesome measurement of the short diameters.

The sizes of the separations of the sieves are always determined from the very last sand which passed through in the course of an analysis, and the results are quite accurate when so obtained. With the elutriations average samples are inspected, and estimates made of the range in size of particles in each portion. Some stray particles both above and below the normal sizes are usually present, and even with the greatest care the result is only an approximation to the truth; still, a series of results made in strictly the same way should be thoroughly satisfactory, notwithstanding possible moderate errors in the absolute sizes.

In applying the foregoing to cement separation it must be borne in mind that the time element plays an important part in cement sieving, the operation being considered finished when not more than 0.05 gram passes a sieve in one minute's shaking, the latter being performed according to specifications. From the cement tester's point of view, this 0.05 gram is the "almost nothing" of the first paragraph quoted above. We have had occasion to measure the diameters of several hundred of these largest particles that pass the 200-mesh sieve just after the sieving has been completed, and we have been unable to determine the average diameters with sufficient accuracy for the purpose of comparing the size of separation of a sieve. Thus two observers with considerable experience in microscopic measurements have found differences of 4 or 5 per cent in their determinations of the average diameters of a large number of the largest particles which have passed a given 200-mesh sieve. Perhaps greater uniformity might have been obtained if the sieving had been continued until "almost nothing" passed. Tests have shown, however, that a very large number of cement particles will pass a 200-mesh sieve after the sieving has been continued for hours, and the time element is therefore an essential part of the sieving test. In one test a sample of the cooperative cement was sieved for about four hours on a standard 200-mesh sieve, after which about a thousand particles passed through in one minute's hand sieving. A similar test was made on another sieve, in which the operation was continued for nine hours. The residue was then sieved by hand for one minute, during which approximately 700 particles passed through.

It is further evident that if the sieving process is continued until only a few particles pass the sieve in a minute's sieving, then these particles must have passed through the largest openings of the sieve, and it has been demonstrated by measurements similar to those recorded in Table 7 that sieving values have no definite relation to the size of the largest openings of a sieve, but must rather depend upon the frequency and distribution of those openings. Fig. 3 shows the character of the cement particles passing a 200-mesh sieve at the end of the ordinary sieving operation.

It must be concluded, therefore, that the comparison of many 200-mesh sieves on the basis of size of separation is impracticable, first, because the size of the largest particles can not bear a close relation to the sieving value, as fineness determinations are made in cement testing; second, because the measurements of the particles are not sufficiently accurate to insure the desired uniformity; and third, on account of the great labor involved.

4. OTHER PROPOSED METHODS OF TESTING SIEVES

Other methods of testing sieves have also been proposed—for example, projection of the sieve on a screen by means of a lantern, or enlarged photographs of the sieve, by means of which the character of the sieve cloth may be conveniently studied. These methods, however, are not essentially different from the microscopic method, and would appear to have no advantage over the latter. From the considerable study which has been made of various methods, it is believed that the actual sieving tests afford the best means of intercomparing and standardizing sieves, and if these are supplemented by a brief microscopic examination to insure the general accuracy and uniformity of the sieve cloth, no further limitations or refinements will be required.

VI. SELECTION OF A STANDARD MATERIAL FOR CHECKING THE SIEVING VALUE OF SIEVES

Various materials, other than cement, have been suggested for use as a standard sample for checking sieves, on the supposition that these materials are less likely to undergo gradual change in their physical properties. Thus the hygroscopic nature of cement and the tendency of the coarser particles to disintegrate and break up into finer particles have been brought forward as objections to the use of cement for this purpose.

1. TESTS OF CEMENT AND OTHER MATERIALS

Accordingly a series of sieving tests were made on several different finely ground materials to compare their suitability as samples of standard fineness for sieve tests. The following materials suggested themselves as being possibly adapted to the purpose and were included in the tests: Cement, Ottawa sand, building sand, trap rock, gravel, white marble, hard-burned red brick, porcelain (ordinary crockery), glazed clay tile, emery, and alumina. All of these materials were first crushed and ground to pass a 20-mesh sieve, if necessary, and were then further ground in laboratory pebble mills to a fineness of about 80 per cent passing the 200-mesh sieve. The powders (including the cement, which was a part of that used in the cooperative tests) were then placed in shallow pans and dried in an electrically heated oven for 24 hours at about 110° C. They were then thoroughly mixed and stored in air-tight jars. On a day when the humidity was low a sufficient number of 50-gram samples were weighed out, put in small tin cans with close-fitting covers, and sealed with adhesive tape until such time as the tests could be carried out. It was originally planned that each of the finely ground materials should be tested on two different standard sieves by each of the three operators, the tests to be made on days when the relative humidity was not higher than 50 per cent. Warm weather had already arrived, however, when the tests were started, and the days of comparatively low humidity were few and far between, so that the program was not fully carried out. It was not deemed worth while to make these tests under the average atmospheric conditions of high humidity that prevail in Washington during the summer months, and accordingly only four tests were made under the desired conditions of each material. The operators each made independent notes on the behavior of the various materials on the sieve and the total time of each test from start to finish was recorded. After the completion of the tests each operator made a list of the materials, arranging them in the order

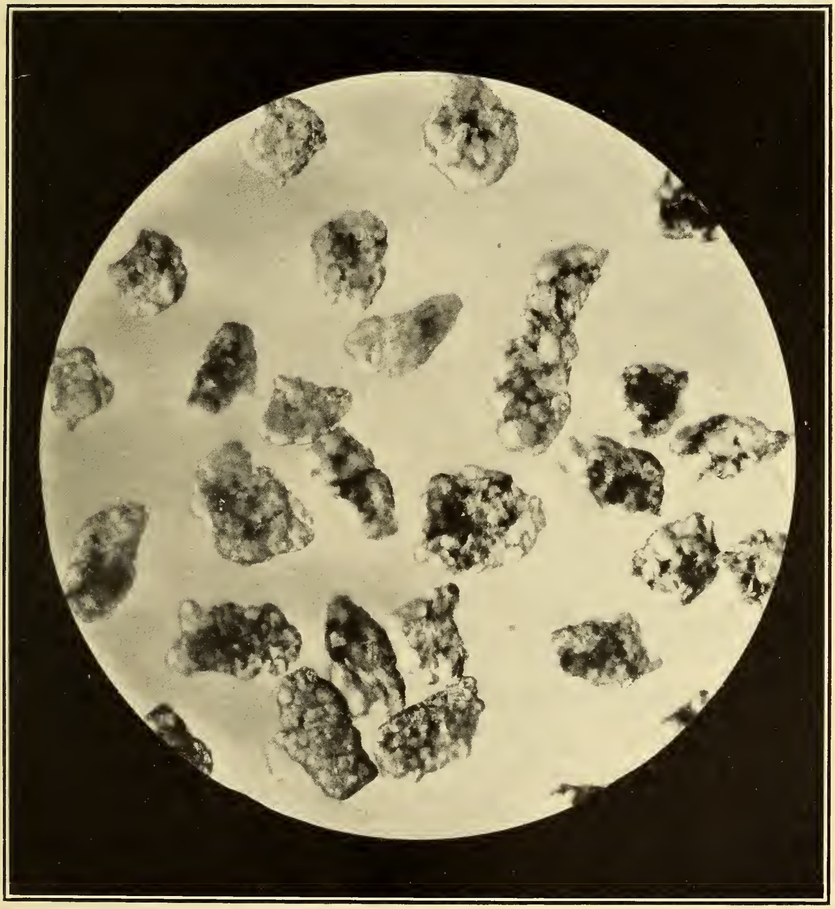

FIG. 3.—*Cement particles passing a No. 200 sieve at the end of the ordinary sieving operation. Magnification, 175 diameters*

of his preference in sieving. These three lists were compared and the operators finally agreed upon the order of preference given in Table 8.

TABLE 8

Results of Comparative Sieving Tests Made by Three Operators on Eleven Different Materials

Material	P on 624		P on 145		S on 145		K on 624		Range in sieving values	Average time (minutes)
	Passed 200 S	Time (minutes)	Passed 200 S	Time (minutes)	Passed 200 S	Time (minutes)	Passed 200 S	Time (minutes)		
1. Cement	76.92	17	77.00	22	77.04	29	76.96	25	0.12	23
2. Brick	77.44	24	78.18	29	77.96	30	78.40	30	0.96	28
3. Marble	76.78	25	77.12	29	77.00	39	77.54	40	0.76	34
4. Sand	80.10	33	80.16	37	80.16	42	79.74	60	0.42	43
5. Gravel	79.00	29	78.64	38	79.04	53	78.94	40	0.40	40
6. Emery	80.84	27	80.48	33	81.00	59	80.60	40	0.52	40
7. Tile	78.64	33	78.88	34	79.26	44	79.34	55	0.70	42
8. Alumina	82.14	35	82.20	42	81.76	45	80.08	80	2.06	50
9. Trap	83.22	26	82.88	35	84.06	46	82.70	45	1.36	38
10. Building sand	83.24	46	82.08	36	82.94	49	82.08	40	1.16	43
11. Porcelain	76.56	46	76.14	26	76.00	73	76.12	40	0.56	46
Average	79.53	31	79.43	33	79.66	46	79.32	45		

A summary of the notes made on the various materials during the sieving tests is as follows:

1. *Cement.*—Fine material passed in two to three minutes. Residue clean. One-minute tests decreased regularly and rapidly. Average time of test, 23 minutes.

2. *Brick.*—Practically no clogging at first. Fine material passed in two to three minutes. Residue clean. One-minute tests decreased regularly and satisfactorily. Average time of test, 28 minutes.

3. *Marble.*—Very slight sticking in sieve at first, but cleared up readily. Residue clean. One-minute tests decreased regularly and rather slowly. Average time of test, 34 minutes.

4. *Standard Sand.*—Slight clogging at first, but cleared up easily. Residue clean. One-minute tests slightly irregular and decreased slowly. Some tendency of particles to stick in sieve at end. Average time of test, 43 minutes.

5. *Gravel.*—Slight clogging, but cleared up after two or three minutes. Residue clean. One-minute tests came down regularly but slowly. One operator reported slight amount of dust in residue. Average time of test, 40 minutes.

6. *Emery.*—Slight clogging at first, but cleared up in three or four minutes. Residue clean. One-minute tests decreased slowly. One operator reported seven or eight one-minute tests not differing much from 0.05 gram. Average time of test, 40 minutes.

7. *Tile.*—Clogged rather badly at beginning. Residue somewhat dusty. One-minute tests decreased slowly and irregularly. Average time of test, 42 minutes.

8. *Alumina.*—Slight clogging at first. Residue clean. One-minute tests decreased slowly, one operator reporting irregularly. Average time of test, 50 minutes.

9. *Trap.*—Clogged badly at first, one operator requiring 25 minutes to get a clean residue. One operator reported irregular one-minute tests. Average time of test, 38 minutes.

10. *Building Sand.*—Clogged badly at beginning, apparently due to clay. Residue not always clean. One-minute tests decreased slowly. One operator reported several minute tests not differing much from 0.05 gram. Average time of test, 43 minutes.

11. *Porcelain.*—Clogged and stuck very badly for many minutes, especially in the first two tests a strong electrical effect was observed, both fine and coarse material sticking to sieve and cover, while dust adhered strongly to under side of sieve and pan. Uniformity of results surprising under the circumstances. Average time of test, 46 minutes.

Comparing the foregoing data it is apparent that cement is to be preferred to all the other materials so far as actual sieving is concerned. The question of moisture absorption does not seem to be of great importance in this connection, for a standard sample of any sort would be issued in a thoroughly dry condition in a sealed container, and would not ordinarily be exposed to dampness at all before using. Nevertheless it would be important to know whether the cement was more affected than the other materials by atmospheric moisture during sieving operations which had to be made under unfavorable atmospheric conditions. To establish the comparative effects of humidity in this way independent tests were made by three operators on the three materials which from the foregoing tests would appear to be most suitable for standard samples, viz, cement, ground quartz sand, and ground marble. Brick was omitted because it could not be readily obtained of a uniform quality. The results of the tests are given in Table 9.

TABLE 9

Effect of High Humidity on the Sieving Values of Cement, Ground Quartz Sand, and Marble

Operator	Material	Results on dry day			Results on damp day			Difference in sieving values
		Per cent passing	Time of test (minutes)	Humidity	Per cent passing	Time of test (minutes)	Humidity	
P on No. 145	Cement	77.00	22	44	76.86	25	92	0.14
	Sand	80.16	37	57	79.04	42	90	1.12
	Marble	77.12	29	57	76.40	32	89	.72
K on No. 624	Cement	76.96	25	60	76.48	25	92	.48
	Sand	79.74	60	53	78.80	45	92	.94
	Marble	77.54	40	35	76.50	35	89	1.04
S on No. 145	Cement	77.04	29	56	76.86	29	87	.18
	Sand	80.16	42	35	79.00	43	85	1.16
	Marble	77.00	39	43	77.38	45	85	− .38

From the data presented in Table 9, both the quartz sand and the ground marble, except in one test, appear to be more affected than the cement by the high humidity. In this particular test (the last in Table 9) the operator reported eight 1-minute tests in which the amounts passing the sieve diminished from 0.06 gram to 0.05 gram. Under such conditions if the balance is out by only a few milligrams the error introduced is considerable. In fact, most of the special materials tested possess this undesirable feature of working down to the finish very slowly, and this in large measure accounts for the longer time required to complete the tests on these materials, and for the greater range in results.

The results given in Table 9 partly serve to explain some erratic results previously obtained with samples of ground quartz which were submitted upon request from three different sources, and recommended as being better adapted than cement for checking sieves. We shall designate these samples simply by their laboratory numbers, 1111, 1161, and 1182, and present the results as obtained.

Sample No. 1111 was submitted as having a fineness of about 80 per cent passing the No. 200 sieve, but was found to pass approximately 88 per cent and was rather too fine for directly comparable results. A number of tests were made on this sample and the following results were obtained:

Operator	Sieve	Observed fineness	Humidity
P	576	87.04	82
P	576	86.82	88
K	576	87.26	(?)
K	576	87.12	(?)
S	576	87.70	84
S	576	87.70	84
S	576	87.66	84

The material was then thoroughly dried out and subsequently tested under more favorable conditions, giving the following results:

Operator	Sieve	Observed fineness	Humidity
P	145	88.14	50
K	624	88.10	58
S	145	88.40	54

Sample 1161 was thoroughly dried and tested under fairly good conditions with the following results:

Operator	Sieve	Observed fineness	Humidity
P	145	76.22	52
K	624	76.20	57
S	145	76.26	54

Sample 1182 was somewhat damp when received, the effect of which is shown in Fig. 4. This was also thoroughly dried and

FIG. 4.—*Showing the hygroscopic nature of finely ground quartz sand. Balling effect on a No. 20 sieve due to absorption of atmospheric moisture*

tested under favorable atmospheric conditions. The results obtained were as follows:

Operator	Sieve	Observed fineness	Humidity
P	145	85.36	51
K	624	85.38	50
S	145	85.10	58

For comparison of the foregoing results, it should be remembered that sieve No. 576 has a correction of about +0.5 per cent on the nearly correct standards No. 145 and No. 624.

These results indicate further that the finely ground quartz is readily affected by atmospheric moisture, and the importance of having standard samples of any sort in a thoroughly dry condition and tested when the humidity is low is evident.

The second objection to cement, that it tends to become finer with age, is frequently referred to as a "well-known" phenomenon, and a number of tests have been made to show the rate of increase in fineness.

Two series of tests were undertaken by the Bureau to establish the importance of this phenomenon, especially in its relation to the use of cement as a standard sample for sieve tests. As the indications of previous tests had led us to believe that fresh and possibly unsound cements show this disintegration or decrepitation of coarse particles much more rapidly during the first few months than at later periods, two cements were selected which had been stored for about a year in the laboratory, and both of which were sound in the high-pressure steam test when received. One of these cements was used in the cooperative sieving tests and the other was a somewhat finer cement of a different brand. The former since the time when it was first mixed (January, 1914) has been bottled up in containers similar to those issued to the laboratories participating in the cooperative tests; the latter has been kept in an ordinary 1-quart mason jar, sealed airtight, except when the tests came due and the requisite number of samples were weighed out for the tests.

In order to introduce as little error as possible in the comparisons, our most experienced operator undertook to make five very careful tests of each cement on the same sieve whenever the tests were desired, the mean of the five determinations on a given date to be taken as the apparent fineness on that date. Whenever the cooperative cement was tested, one 50-gram sample was taken from each of five different bottles, thus affording a comparison of the uniformity of the cement as well as its rate of change in fineness. The results are presented herewith in detail.

Fineness Determinations on Cement No. 1 (Cooperative Cement). The Results Were Obtained on Sieve No. 576

Jan. 26, 1914	Feb. 25, 1914	Mar. 25, 1914	May 26, 1914 [a]
76.40	76.62	76.52	76.38
76.43	76.42	76.42	76.36
76.26	76.44	76.58	76.34
76.29	76.58	76.36	76.36
76.68	76.54	76.46	76.20
Mean... 76.41	76.52	76.47	76.33

Fineness Determinations on Cement No. 2 with Sieve No. 576

Nov. 29, 1913	Feb. 21, 1914	May 29 and June 2, 1914
78.50	78.62	[b] 78.44
78.52	78.70	[b] 78.36
78.44	78.86	[b] 78.42
78.40	78.70	[c] 78.58
78.50	78.60	[c] 78.66
Mean........ 78.47	78.70	78.49

[a] Humidity of all tests on this date 61 per cent.
[b] Humidity (May 29), 68 to 71 per cent.
[c] Humidity (June 2), 39 to 40 per cent.

A comparison of these results shows practically no change or a slight *decrease* in fineness with age. This slight apparent decrease in fineness is probably due to some peculiarity of conditions. The first explanation that might be suggested is that the sieve has become dirty, or considerably plugged with particles wedged in the openings. The sieve is in excellent condition, however, and apparently as good as new. The most probable explanation lies in the more or less unknown effects of humidity, which were largely disregarded in the earlier tests. The only precautions taken were to make the tests on days when the weather was fair, but this does not seem to have been sufficient. As previously stated the reports of all sieving tests are now accompanied by humidity records, but we can only state at present that humidity appears to have a greater effect on the sieving tests than has commonly been supposed. We know in general that the lowest humidity occurs in mid-winter (in our laboratories), whereas a high average humidity obtains during the summer. We are, therefore, unable to conclude at the present time that these cements are becoming finer with age, and there is no indication that the cements have changed appreciably in six months. Further tests will be made on these samples from time to time, but we believe the results indicate that there is no valid objection to the use of a cement of this character as a standard fineness sample, and all things considered, such a sample is much to be preferred to any other because it has all the characteristics of grain which are peculiar to cement.

2. TESTS OF NORMAL CEMENT WITH THE DUST REMOVED

In connection with the work which has been done at the Bureau on mechanical analysis of cement by means of air separation a number of sieving tests have been made on samples of cement from which the fine dust has been blown out in an improvised apparatus, and comparisons have been made between these and the ordinary sieving tests on normal samples. The one very great advantage of making the sieving test on a blown sample, is the perfect cleanliness and quickness of the operation. All troubles arising from the presence of dust are thus avoided and the operation in general requires only one-half the time of the ordinary fineness determination. It seems probable also that this offers a means of avoiding humidity troubles, for the latter are undoubtedly due in large measure to the presence of the very fine material.

There are some objections, however, to the use of blown cements for standard sieving samples, the most important of which are the following:

If the dust be removed from a considerable quantity of cement in one operation the granular residue can not be mixed in such a manner as to insure the required uniformity to permit of taking small samples, as the particles of various size segregate readily. The presence of the fine material or flour seems to prevent this segregation of different sized particles, therefore it has been found necessary to blow out the 50-gram samples separately.

Comparative sieving tests on blown and unblown samples have shown that the former almost invariably show a smaller residue on the sieve than the latter, and this does not appear to be due to abrasion of the particles during the process of blowing, but rather to the greater cleanliness of the blown sample which permits it to pass through the sieve more rapidly. This difference in rapidity of sieving more than offsets the increased amount of unblown cement which it might be expected would pass the sieve, owing to the longer time required for sieving the latter. The difference has not been found to be uniform. It varies from 0.1 per cent to 0.5 per cent or even more in directly comparative tests. It is possible, however, that the variation occurs more with the unblown sample than with the blown sample.

Further tests will probably be made in the near future when a more suitable apparatus for blowing the samples is obtained. Careful comparisons will then readily show whether the blown samples are reliable for sieving tests, and it is anticipated that they may finally be found preferable to the original samples for the purpose in view. Should this prove to be the case, the additional labor of blowing out the individual samples would be more than offset by the adaptability of the blown samples for repeated check tests.

VII. ADOPTION AND MAINTENANCE OF A STANDARD VALUE OF FINENESS

1. THE BASIS FOR ADOPTION OF A STANDARD

It was first proposed that a standard value of fineness should be adopted from the results of the cooperative sieving tests by comparing the results obtained on those sieves which were nearest to the ideal 200-mesh sieve as indicated by the certification measurements. This plan was abandoned for the two reasons which have already been intimated. First, individual results from outside laboratories were found to be unreliable in a number of cases, and it was therefore deemed inadvisable to accept any of these results without assurance that the tests had been made carefully and in accord with the specifications; second, the results obtained by the Bureau on the so-called "good sieves" showed such a large range that this could not be regarded as a satisfactory means of selecting a standard. Moreover, an examination of a very large number of standard sieves has shown that there is probably no such thing as an ideal standard sieve in existence; that is, no sieve has ever been found which has even approximately uniform openings of 0.0029 inch size. The sieving value of an ideal 200-mesh sieve therefore can not be established with any certainty, and the adoption of a standard value of fineness must be more or less arbitrary.

The fineness of the cooperative cement was finally adopted as 77 per cent passing the standard 200-mesh sieve, this value being, so far as anyone knows at the present time, as good an estimate of the true fineness as it is possible to make. The considerations which led to the adoption of this value are briefly as follows: When Technologic Paper No. 29[6] was published, the sieve which was then believed to be nearest to the ideal was found to have a sieving value of 80.30 per cent on the cement used at that time. This agreed very closely with our own standards, which, in testing the cooperative cement showed the average fineness of the latter to be approximately 76.5 per cent. The results obtained with the cooperative cement on later selected sieves, however, showed an average value ranging between 76.5 and 77.5 per cent. With no other means of deducing the true value, 77 per cent was therefore arbitrarily assumed to be the true fineness of the cooperative cement on the ideal 200-mesh sieve. With our present knowledge of the large irregularities which occur in all 200-mesh sieves, the sieving value of a given sieve is merely accidental, as far as our ability to estimate this value is concerned, and it is therefore to be regarded as an interesting coincidence that sieve No. 79, which might be selected as the best of the sieves in Table 5, has a sieving value very close to the adopted standard.

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[6] Technologic Paper No. 29, Bureau of Standards, 1913.

2. THE MAINTENANCE OF A STANDARD OF FINENESS AND THE CARE OF STANDARD SIEVES

In order to insure a greater uniformity in fineness determinations, and to enable other investigators to make comparative tests, the Bureau of Standards will henceforth maintain a standard of fineness.

The real test of the preservation of fineness standards will consist in retests from time to time of a number of sieves which are in substantial agreement with the adopted standard and are set aside as fundamental standards. It is not anticipated that any great difficulty will be experienced in applying successfully small corrections to care for sieve errors and "personal equations," nor in maintaining the standard from one set of sieves to another. It seems to be wholly a question of careful work and proper protection and care of the standard sieves.

It is impossible to state how long a sieve may be expected to preserve its sieving value unimpaired, but when properly used and properly cared for it should be reliable for a number of years. All cement testing laboratories should preserve standards of their own not only for checking up their routine sieves, but for the avoidance of possible disputes and uncertainties regarding their fineness determinations. Proper care of these primary standards is essential, and in connection therewith the following suggestions are offered:

1. When not in use the primary standard should always be inclosed in its pan and cover, and preferably kept in a clean, dry cabinet.

2. The primary standard should never be used for routine work, nor on a mechanical shaker, and should preferably be used only for sieving well dried samples of cement.

3. No washers, shot, or other devices for hastening the sieving process should ever be used on the primary standard.

4. Use of the primary standard in damp weather is to be avoided whenever possible, and at all times the sieve should be kept clean and free from dust. Cement samples or residues should never be left on the sieve longer than necessary.

It is believed that if these precautions are observed a primary standard will maintain the constancy of its sieving value for years.

3. PRELIMINARY TESTS OF THE BUREAU'S PRIMARY STANDARDS

Three of the standard sieves now owned by the Bureau of Standards have been set aside as temporary fundamental standards, and preliminary tests have been made on these sieves with cements of different fineness. The results of these tests are here given to show the order of magnitude of the variations which may be expected in similar tests. Each of the determinations is the mean of three independent tests by three observers, exactly as obtained.

Standard number	Cement No. 406	Cement No. 735	Cement No. 721
145	76.84	83.22	87.45
146	76.83	83.45	87.44
624	76.95	83.20	87.32
Mean	76.87	83.32	87.40

These results indicate that similar standards will give very reliable and consistent check determinations, and it is believed that new standards can be based on these and maintained with the same relative degree of accuracy. It is observed that these three sieves have a slight correction to the adopted standard (Cement No. 406 is that used in the cooperative tests) and an endeavor will be made to replace them with more exact standards as opportunity offers.

4. STANDARD SAMPLES

In the future the Bureau will be prepared to furnish standard samples of cement at a nominal price, for tests of sieves in other laboratories. The fineness of these samples will be guaranteed to within 0.2 per cent on the fundamental standards. The sieving values of all new sieves with one sample of cement will in the future be given with the certificates of the standardized sieves, but while these values will in general be correct within 0.2 or 0.3 per cent they will probably be guaranteed only within 0.5 per cent. One reason for this rather wide limit is that the routine testing of sieves will hardly permit of more than two or three determinations, without making the cost of standardizing undesirably high. A second and more important reason is that the sieving values of many sieves may have to be determined under unfavorable atmospheric conditions which can not always be readily avoided. In most cases, however, the sieving values will be sufficiently close for the operator to determine whether the standard samples furnished are being properly used, and whether appreciable discrepancies are entering into his fineness determinations due to carelessness or personal peculiarities in manipulating the sieve.

This standardizing test will ordinarily be made with a cement having a fineness between 75 and 80 per cent passing the No. 200 sieve, and will furnish a correction factor which will only be directly applicable to cements of similar fineness. If for investigative purposes it is desired to know the correction factor for a greater range on the sieve, tests should be made with two cements of widely different fineness which will establish a calibration curve as described in the following section.

VIII. THE CORRECTION TO THE SIEVING VALUES OF STANDARD SIEVES

1. THE USE OF A CONSTANT CORRECTION

The correction to the sieving value of a sieve as determined from standardization tests is of special importance only from two aspects, first, it should be known and applied in all cases requiring the use of the primary standard; second, it should be known and applied whenever approximately accurate determinations are wanted, for example, in tests of samples which are about at the limit established by the specifications. In the latter case the sieve correction may be regarded as a constant when determined on a standard sample of which about 75 per cent passes the 200-mesh sieve; in most routine tests also, the use of a constant correction factor will give sufficiently close results. To illustrate, let it be assumed that a certain sieve indicated the fineness of the cooperative cement to be 78.5 per cent. From the adopted standard of 77 per cent for the cement the apparent correction to the sieve would be —1.5 per cent. If this sieve were used entirely for checking samples of cement purchased on a specification requiring a fineness of 75 to 80 per cent, the correction of —1.5 per cent would be sufficiently exact for all determinations.

Strictly, however, the sieve correction is not a constant but diminishes with increasing fineness. From the observations thus far made, it appears that two calibrations with standard samples differeing preferably by 10 per cent or more in fineness are required to enable one to determine the varying correction to a sieve, and it has been found that sieves with widely varying sieving values can thus be made to give quite accurate determinations over all ordinary ranges of fineness.

2. CALIBRATION CURVES FOR SIEVES

The method suggested in the preceding paragraph for determining the proper correction to sieves involves the use of simple calibration curves which may be constructed as follows:

On a sheet of mm cross section paper 30 cm x 30 cm or larger, lay off on the horizontal axis the true fineness, expressed as per cent of total cement passing the ideal 200-mesh sieve. Mark the origin 100 per cent, 5 centimeters to the right 95 per cent, 10 centimeters to the right 90 per cent, etc. Lay off on the vertical axis residues actually obtained in sieving tests, expressed in grams. Mark the origin 0, two centimeters above the origin 1 gram, 4 centimeters above the origin 2 grams, etc. The vertical axis may be also marked off in the same manner as the horizontal axis, the percentage here being *apparent* fineness. Thus the 95 per cent mark will coincide with the 2.5 gram mark, the 90 per cent mark with the 5-gram mark, etc.

Let us assume that a given sieve has been standardized with two standard samples of 75 per cent and 85 per cent true fineness, the apparent fineness observed on the sieve in question being 76.50 per cent and 86 per cent. Taking the true values as abscissæ and the apparent values as ordinates, locate two points on the diagram. The straight line passing through these points is the calibration curve required.

The use of the calibration curve is very simple. In any subsequent fineness test, locate on the vertical axis the number of grams residue obtained (or the apparent fineness in per cent). The horizontal through this point will cut the calibration curve at a point whose abscissa is the true fineness required.

To illustrate the use of this graphical method, calibration curves are drawn in Fig. 5 for four sieves having considerably different corrections. One of the standard samples on which these curves are based is that used in the cooperative tests, with a true fineness of 77 per cent.

The apparent fineness of this cement on the four sieves was as follows: No. 66, 79.11 per cent; No. 132, 78.35 per cent; No. 590, 75.69 per cent; No. 294, 74.49 per cent. These four values determine one point on each of the calibration curves, as already explained.

The second points of the curves for sieves No. 66 and No. 294 were determined on a cement whose true fineness on the fundamental standards was 86.63 per cent. The apparent fineness of the latter on these sieves was, No. 66, 88.13; No. 294, 85.19.

The second points of the curves for sieves No. 132 and No. 590 were determined on a cement whose true fineness on the fundamental standards was 87.40 per cent. The apparent fineness of the latter on these two sieves was, No. 132, 88.36; No. 590, 86.69.

Sieving tests were then made with each of these sieves on a number of cements of known fineness, the results of which gave checks on the reliability of the results obtained from the calibration curves.

For comparison, the true fineness of the cements as determined on the fundamental standards, and the fineness as determined graphically from the calibration curves is given in Table 10.

TABLE 10

Comparison of Fineness Determinations Obtained by the Use of Calibration Curves with the Actual Determinations on the Fundamental Standards

Sieve No.	Cement No.	Observed fineness	Calculated fineness from calibration curves	True fineness on fundamental standards	Difference between true and calculated fineness
66	710	82.94	81.1	80.81	0.29
66	727	76.52	74.2	73.97	.23
132	735	84.63	83.55	83.32	.23
132	720	75.22	73.7	74.00	.30
590	735	82.25	83.2	83.32	.12
590	720	72.54	74.0	74.00	.00
294	710	78.65	80.75	80.81	.06
294	727	71.37	74.1	73.97	.13

The last column of Table 10 shows a maximum variation between calculated and true values of 0.3 per cent, which must be considered quite satisfactory, especially in view of the fact that

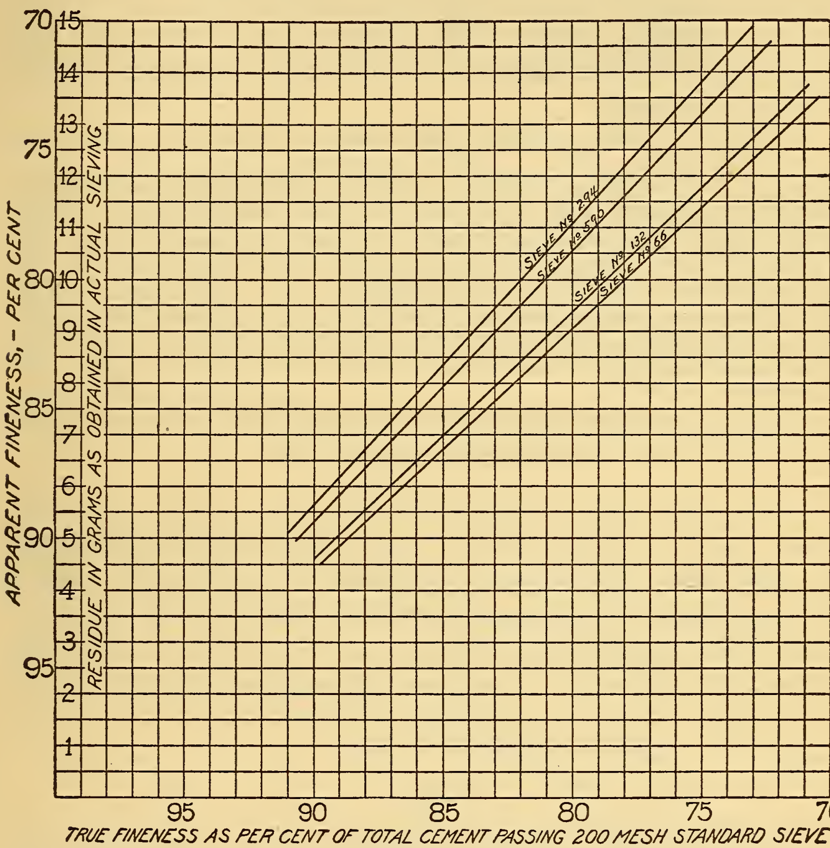

FIG. 5.—*Reproduction of calibration curves of four No. 200 sieves, plotted on mm cross section paper 30 cm×30 cm*

sieves Nos. 66, 132, and 294 fail to meet the requirements of the new specification for standard sieves.

It will be observed in Fig. 5 that the calibration curves trend toward the origin. The curves for sieves Nos. 294 and 590, if extended, pass very close to the origin, whereas the curves for sieves Nos. 132 and 66 run somewhat below it. This fact suggests a method of drawing an approximate calibration curve for any sieve which has been tested with a single standard sample, which as previously explained, determines one point of such a curve. If a straight line be drawn through this point and the origin, a calibration curve is obtained which in the case of most sieves will yield results which are probably correct within 0.5 per cent over all ordinary ranges of fineness found with cements. It is, however, less reliable than the one based on tests with two standard samples of different fineness.

Calibration curves are, of course, chiefly important in the case of sieves having large corrections, and it is anticipated that their greatest usefulness will be found in their adaptation to those sieves which have previously been certified as standard sieves but fail to meet the new sieving requirements. The calibration curves also afford the most convenient and practical means for getting directly the best results obtainable from any sieve, whether it be "standard" or not.

It may be pointed out that a calibration curve can be represented analytically by an equation of the form

$$T = KA + C,$$

where T and A are the true and apparent fineness, respectively, but here more conveniently expressed as per cent of residue than per cent of total cement passing the sieve. K is the reciprocal of the slope of the calibration curve and C is the intercept on the horizontal axis. If only an approximate calibration curve is employed, which, as previously explained, passes through the origin, $C = O$, and the equation becomes

$$T = KA,$$

where K is the ratio of the true fineness to the apparent fineness of the standard sample used, both being expressed as per cent of residue.

In case the calibration curve is determined from tests of two standard samples the equation of the curve may be shown to be

$$T = \frac{T_1 - T_2}{A_1 - A_2} A - \frac{T_1 - T_2}{A_1 - A_2} A_2 + T_2,$$

where T_1 and A_1 are the true and apparent per cent residues of the coarser sample, and T_2 and A_2 are the true and apparent per cent residues of the finer sample, respectively.

The application and use of such an equation may be illustrated by data from tests on sieve No. 66 above. Thus the true fineness of the coarser standard sample was 77.00, that of the finer sample was 86.63. The apparent fineness of the coarser standard sample was 79.11, that of the finer sample was 88.13. Hence $T_1 = 23.00$, $T_2 = 13.37$, $A_1 = 20.89$, $A_2 = 11.87$. Substituting these in the general equation, we have

$$T = 1.07\ A + 0.67,$$

the equation of the calibration curve for sieve No. 66. From any test on this sieve the true fineness is obtained by substituting for A the apparent fineness (expressed as per cent of residue) and solving for T. For example, let us check up the first test recorded in Table 10 on sieve No. 66. Here the observed fineness was 82.94 per cent, whence $A = 17.06$. Substituting this value in the above equation,

$$T = 18.25 + 0.67 = 18.92.$$

The true fineness is therefore 81.08, which agrees with the value obtained from the curve.

It is thus shown that a very approximately correct fineness determination may be obtained on any sieve, with the aid of graphical or analytical methods, but the former will be found much more convenient in the laboratory.

3. TOLERANCES

On the basis of the work reported in Technologic Paper No. 29, a tolerance of 1 per cent from the specification was recommended in fineness determinations. It has been shown that unless allowance is also made for the variations of standard sieves this tolerance is not sufficiently large. In the future, however, standard sieves will be certified as to sieving values, and standard samples will be available for checking up these values at any time. A tolerance of 1 per cent would therefore appear to be ample to include all unknown and legitimate errors, even in routine testing. In check tests all laboratories should be in a position to guarantee their work well within this limit and with extreme care the error should not be in excess of 0.5 per cent. The Bureau therefore recommends that a tolerance of 1 per cent be allowed in all routine tests, and a tolerance of 0.5 per cent in all cases of dispute or other important tests, where extreme care is used in making the determination.

IX. A REVISED SPECIFICATION FOR STANDARD 200-MESH SIEVES

On the basis of the investigation reported herewith a revised specification for standard 200-mesh sieves will be adopted by the Bureau of Standards October 1, 1914, and will replace the specifications for these sieves issued in 1912.[7] The revised specification is as follows:

BUREAU OF STANDARDS SPECIFICATIONS

FOR NO. 200 CEMENT SIEVES

Wire cloth for standard sieves for cement shall be woven (not twilled) from brass, bronze, or other suitable wire and mounted on frames without distortion. The sieve frames shall be circular, about 20 cm (7.87 inches) in diameter, 6 cm (2.36 inches) high, and provided with a pan about 5 cm (1.97 inches) deep and a cover.

NO. 200 CEMENT SIEVE, 0.0029-INCH OPENING

The No. 200 sieve should have 200 wires per inch and the number of wires in any whole inch shall not be outside the limits 192 to 208. No opening between adjacent parallel wires shall be more than 0.0050 inch in width.

The diameter of the wire should be 0.0021 inch, and the average diameter shall not be outside the limits 0.0019 to 0.0023 inch.

The sieving value of the sieve, as determined by sieving tests made in conformity with the standard specifications for these tests on a standardized cement which has a fineness of 75 to 80 per cent passing the No. 200 sieve, or on other similarly graded material, shall not show a variation of more than 1.5 per cent from the standards maintained at the Bureau of Standards.

The Bureau also reserves the right to reject sieves for obvious imperfections in the sieve cloth or its mounting, as, for example, punctured, loose, or wavy cloth, imperfections in soldering, etc.

A brief discussion of the new specifications will explain the grounds on which the new requirements have been established.

It has been shown that the uniformity of the sieve cloth is not established by the regularity in the number of meshes per linear inch or even per quarter inch, hence the latter requirements have been omitted and more liberal limits have been established for

[7] Circular No. 39, Bureau of Standards.

the whole inch intervals. The variation in meshes from 192 to 208 corresponds very nearly to the variation in wire diameters from 0.0019 inch to 0.0023 inch in its effect on the size of the openings; hence limits for meshes and wire diameters are more consistent than formerly.

The maximum allowable opening between adjacent parallel wires has been set at 0.0050 inch. This rather high limit has been specified because practically all sieves have some openings greater than 0.0040 inch, whereas comparatively few have openings larger than 0.0050 inch. It is very desirable, however, to reduce this limit, as these excessively large openings appear to be largely responsible for the variations in sieves, and it is believed that this restriction can be easily met.

The most important restriction, so far as the purchaser is concerned, is that relating to the sieving value. The maximum allowable variation of 1.5 per cent from the standard will also be more just to the manufacturer, as many sieves have been rejected in the past which are fully as reliable for sieving purposes as the best standard sieves in existence. With a proper use of the sieve corrections which will henceforth be available, a much greater uniformity in fineness determinations should be obtained.

The general rejection clause, relating to obvious imperfections in sieves, has been added because its need has frequently been felt, and it is believed that manufacturers will not have reason to complain at any rejections which are likely to be made on this account.

In conclusion, it may be stated that similar changes in specifications for other sieves have been considered, especially for the standard 100-mesh sieve. The necessity for these further changes, however, is far less urgent, partly for the reason that the coarser sieves are relatively much more uniform than the 200-mesh sieve, and partly because the great majority of cements which meet the 200-mesh sieve requirements are well within the 100-mesh sieve requirements, and it is not, therefore, deemed advisable to introduce a change at this time.

X. SUMMARY

This report on the standardization of 200-mesh sieves has involved a considerable amount of time and labor, probably more than its value would justify in the opinion of many. It is, however, only a beginning of the study of the general subject of fineness of cements. In Technologic Paper No. 29 it was stated that air separation may offer a more satisfactory means of determining fineness than mechanical sieving. Further development of the air analyzer has shown that it is capable of giving complete and reliable mechanical analyses of cements, but its present form does not permit its general use for routine purposes. It will, however, separate the finer grades which can not be separated by any sieve, and it is hoped that it may be developed for use in routine work. While the sieve is not an instrument of high precision, and while it is a tax on the patience of those who are obliged to use it, it is nevertheless important in cement testing and is capable of higher duty, not only by reason of further improvement in manufacture, but also of better manipulation.

The investigation has established the following:

1. The specifications for standard sieves have considerably improved the quality of sieves in recent years, but the methods of standardizing based on these specifications have been found inadequate to insure the performance of 200-mesh sieves as actually used in cement testing. Therefore a revised specification for standard 200-mesh sieves, based on the sieving value of sieves is found desirable.

2. A study of the results of many sieving tests by careful and experienced operators has shown that single fineness determinations made under satisfactory conditions are rarely in error by 0.5 per cent, that the "personal equations" of such operators are of the order of 0.1 to 0.2 per cent and that high-grade work requires only careful attention to the essentials of the sieving operation.

3. Cooperative tests with 80 laboratories have shown that sieves bearing the Bureau of Standard's seal vary by 5 per cent or more in their sieving values, although the majority show a range of not more than 3 per cent. Check tests on a number of sieves tested in the Bureau laboratory and in other laboratories

show that these tests are often carelessly performed, with little attention to the directions for sieving.

4. Four methods of standardizing 200-mesh sieves have been investigated, with the result that, as these sieves are now being manufactured, the sieving tests, supplemented by a brief examination of the sieve cloth to determine its general uniformity, is the most logical and reliable method.

5. A well burned and aged cement in comparison with several other finely ground materials, appears to be best adapted for testing sieves in the form of standard samples of known fineness.

6. A standard of fineness has been adopted, and standard samples of cement will henceforth be available to any who desire to check up their own sieves by this standard.[8]

7. Methods have been outlined for applying the proper corrections to sieving values of sieves based on the fundamental standards.

8. It is recommended that a tolerance of 1 per cent from the specification requirement be allowed in routine fineness determinations, and a tolerance of 0.5 per cent be allowed for check determinations and other important work where extremely careful work is done, due allowance having been made for sieve calibration.

9. The changes in the revised specifications for standard 200-mesh sieves have been taken up in detail, and the reasons for the adoption of these changes have been given.

10. There are certain features of this problem which might be given further study, such as (1) methods of improving the quality of the sieve cloth, especially in the spacing of the warp wires, (2) methods of shortening the sieving process without sacrificing accuracy, (3) the validity of the straight line calibration curve for sieves, (4) the use of blown samples for standardizing sieves, (5) the effect of atmospheric humidity on sieving determinations.

WASHINGTON, July 30, 1914.

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[8] A 160-gram sample of cement guaranteed to within 0.2 per cent on the fundamental standards may be obtained for 25 cents. Address Director, Bureau of Standards, Washington, D. C.